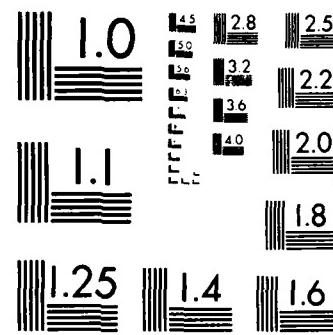


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A THEORETICAL STUDY OF ENHANCED SMITH-PURCELL RADIATION
FROM A BIGRATING

(2)

FINAL REPORT

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JULY 15, 1987

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A theory has been developed of the Smith-Furcell diffraction radiation from a beam of point charges passing over a finitely conducting hirrating surface, with arbitrary orientation of the beam relative to the hirrating axes. The beam's field can resonantly excite one or more surface-plasmon-polaritons, which the hirrating can then decouple into a single outward radiating wave at any given angle and frequency. This process enhances the radiated power by two or three orders of magnitude in the real direction.		

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20. (cont.)

Numerical implementation of the theory has shown that there is an optimal grating height at which this surface-plasmon enhanced radiation peak is at a maximum. This work has also shown that a sinusoidal bigrating, forming a rectangular lattice, can yield an added enhancement, through two-plasmon excitation, when compared to the radiation from a classical grating (periodic in one direction).

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The Smith-Purcell effect — electromagnetic radiation (diffraction radiation) from an electron beam passing above a metal grating surface — has been used for some time to generate millimeter waves in a free electron laser called an Orotron.⁽¹⁾ Recently, the possibility of creating a solid state Orotron, using currents in the inversion layers of MOSFET devices, for example, has been proposed. The idea of using the Smith-Purcell effect to produce coherent UV and soft x-ray radiation with nonrelativistic, i.e., kilovolt, electron beams has also been suggested. Since the underlying Smith-Purcell process is inherently weak, mechanisms to enhance the process are being sought. The resonant excitation of surface plasmons by the electron beam has been shown theoretically to yield an enhancement of two to three orders of magnitude in the radiated power.⁽²⁾ In the proposal for this project it was suggested that a bigrating surface (periodic in two directions) should yield added plasmon enhancements over those found from a classical grating (periodic in one direction).

It was the objective of this work to develop a theory for determining the power radiated from a beam of charged particles passing over a conducting bigrating surface, with arbitrary orientation of the beam direction relative to the grating axes, and then to implement the theory numerically to determine the optimization conditions for the plasmon enhancements.

The theory of Smith-Purcell radiation from a bigrating, on a conducting surface, was completed in its analytic formulation, as



proposed. The starting point of this theory follows the ideas of Toraldo di Francia⁽³⁾ and of van den Berg.⁽⁴⁾ The electric field due to a point charge moving parallel to a surface, with arbitrary direction relative to the bigrating axes, is Fourier decomposed. Each Fourier amplitude is expressed in terms of its p- and s-components, so that it can be treated as an incident wave in an existing theory for the diffraction of light from a conducting bigrating surface.⁽⁵⁾ The conductor here is described by a complex dielectric function. The total scattered electric field is expressed as a Fourier integral over the response of the surface to each of the incident waves. The Poynting vector due to the scattered waves is then determined, and is used to find the total radiated power from the surface. The radiated power from a current of charged particles is obtained by making an incoherent superposition of the single-particle results.

The Fourier integral which expresses this radiated power is recast as an integral over scattering angles, thus allowing one to identify the radiated energy per unit solid angle. In the present theory, the relationship between the scattering angles, on the one hand, and the incident frequency and wavevector and the scattering vector (i.e., reciprocal lattice vector defined by the bigrating periodicity), on the other hand, allows one to identify the terms in the power-integral that correspond to the resonant excitation of surface-plasmon-polaritons. These excitations will give resonances in the radiated power. It is thus possible to identify the kinematical conditions that will give an added enhancement in

the radiation from a bigrating over that from a classical grating.

The field due to the beam can simultaneously excite four surface-plasmons on a bigrating, whereas it can excite only two on a classical grating. The excitation of the surface plasmons can be either a direct process, i.e., zeroth order in the corrugation strength (the ratio of the grating amplitude to period), or first order (or higher). The decoupling of the surface plasmon from the surface into the outward radiating field is a first order (or higher) process; so that the entire excitation-decoupling process can be first or second order. The second order processes were not found to give any additional enhancements in the radiation. Two surface plasmons can be *directly* excited (zeroth order) by the beam, and then a bigrating can simultaneously decouple both from the surface, in a first order process, whereas a classical grating can decouple only one surface-plasmon. The bigrating thus can create a two-surface-plasmon resonance in an overall first-order process.

The expression for the radiated power contains a decaying exponential of the grating amplitude (arising from the evanescent nature of the incident field from the beam). To the lowest order of approximation the exponential would be multiplied by the corrugation strength, in the case of the (direct excitation) first order processes. For the case of a silver surface, as used for the present numerical studies, the function given by the exponential of the grating amplitude times that amplitude has a maximum for a corrugation strength of around 0.08 .

Numerical studies were performed for classical gratings and bigratings, both with a Drude dielectric constant and with the dielectric constant corresponding to the experimentally determined optical constants for silver. The grating profiles were taken to be sinusoidal. Particle velocities between 0.5 and 0.8 times the velocity of light were employed. In the case of Ag, the grating periods and particle velocities were chosen so that the plasmon resonance peak was consistently at a wavelength of 348 nm and at a direction of emergence normal to the surface. The full numerical studies confirmed the simple argument that for maximum power radiated into a given direction at this given frequency, the optimum corrugation strength is 0.08. The enhancement itself is over two orders of magnitude in the plasmon peak [with a peak value of 1.4 mW/A — i.e., 1.4 mW per steradian, per m^2 of beam (parallel to surface), per Amp/m^2 of current density].

Under conditions in which two surface-plasmons are excited and decoupled in a first order process, the bigrating was seen to give an added enhancement over the classical grating, but only when the bigrating forms a rectangular lattice (so as to reduce the angle between the propagation direction of the incident component-wave that excites the surface plasmon and the direction of the particle velocity). The particular ratio of periods of the rectangular lattice that will optimize the radiation is yet to be determined, but the limit on the added enhancement due to the bigrating is clearly a factor of two.

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